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Field Demonstration Comparing Damage to Rural Saskatchewan Roads Caused by Optimised and Normal Highway Truck Tire Pressures

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Abstract

This paper documents the results of a field demonstration to determine if a reduction in road damage occurs when trucks use optimised (reduced) tire inflation pressures instead of normal highway pressures on load sensitive roads. Research done by road authorities in other parts of North America has indicated that optimising truck tire pressures can significantly reduce the damage they cause to lower standard roads. This trial was co-sponsored by the Saskatchewan Department of Highways and Transportation, Saskatchewan Wheat Pool, and Agriculture and Agri-Food Canada through the Canada Agri-Infrastructure Program (CAIP). The authors wish to also acknowledge and thank the Rural Municipality of Walpole for allowing the use of the roads for the demonstration. During the trial two groups of identically configured, commercial, grain trucks were cycled over comparable, adjacent haul routes stopping periodically to assess road damage or to complete road maintenance. Located near Carlyle, Saskatchewan, the two test circuits included sections of thin membrane-surfaced (pavement) highway and clay-capped "Local" or "Main Farm Access" roads, and shared a two-lane, gravel-over-clay cap "Primary Grid" road. One group of trucks used normal highway tire pressures and the other used inflation pressures optimised for their load and speed. The objective of this trial was to observe differences in road damage (including washboard development, rutting, and surface cracking), fuel consumption, and tire heating resulting from the use of optimised tire inflation pressures.

1.0 INTRODUCTION

Since 1995, an initiative of Saskatchewan Department of Highways and Transportation (SDHT) has permitted some truck fleets to operate with primary-highway axle weights on provincial secondary highways provided that the trucks operated within the requirements of the Transportation Partnership Program which included in some cases operating with optimised tire pressures. Tire pressures are optimised by adjusting them to correspond with changes in the road condition, tire loading and/or operating speed that occur during operations. Tire inflation pressures are adjusted to match the tire manufacturers' guidelines using a tire pressure control system (TPCS). A TPCS is an on-board, electro-mechanical system that provides a fast, convenient way for drivers to monitor and adjust tire pressures while driving. The underlying premise of this SDHT initiative is that optimising truck tire inflation pressures significantly improves the road friendliness of the trucks (Anonymous (1987), Smith (1993), Sweet (1994), Brown et al. (1997), and Bradley (1998)) and compensates for the increase in axle load.

The objective of this field trial was to demonstrate the difference in road impacts between trucks operated with optimised tire inflation pressures versus identical trucks operated with normal highway tire inflation pressures. SDHT, Agriculture and Agri-Food Canada through the Canadian Agri-Infrastructure Program (CAIP), and Saskatchewan Wheat Pool sponsored this demonstration project. The Rural Municipality of Walpole co-operated by permitting the trial to take place on its roads. The suppliers of the TPCS (Tire Pressure Control International Ltd.) and the truck navigational system (SOO Software Inc.) also provided logistical and technical assistance. Michelin North America (Canada) Inc. approved the weight/speed/inflation pressure settings used in the demonstration and measured tire surface temperatures during the demonstration.

An advisory committee provided guidance on test design and scope. The committee included representatives from the following groups: Saskatchewan Association of Rural Municipalities, Saskatchewan Trucking Association, Saskatchewan Wheat Pool, University of Regina, Tire Pressure Control International, Forest Engineering Research Institute of Canada (FERIC), SDHT, and two Area Transportation Planning Committees located in Saskatchewan.

2.0 METHODOLOGY

The demonstration trial was conducted in the Rural Municipality of Walpole located five km east of the town of Wawota. Two adjacent test circuits were established on local roads of varied standards (Figure 1). The test circuits consisted of 3.2 km of Highway 48 (a thin membrane surfaced (TMS) pavement), 4.8 km of Grid 601 (a Primary Grid road), and eight km of Local or Main Farm Access (MFA) roads. The Grid 601 road section was common to both test circuits and had two lanes. The Grid 601 road had a 9 m-wide surface consisting of a thin gravel layer (for traction in wet weather) on an approximately 15 cm-thick clay cap, over a subgrade lift of native material. The MFA and Local roads had similar running surface widths (about 6.5 m), and thinner clay caps. However, the MFA road was constructed with a higher subgrade lift than the Local road, which ensured better drainage. The two groups of test trucks ran in opposite directions on Grid 601, in separate lanes. Extensive rutting on Highway 48 was repaired prior to the demonstration.

A variety of measurements were gathered on the test road sections pre- and post-demonstration in order to quantify changes to road structure; and to explain observed differences in road performance. Soil tests (i.e., dynamic cone penetrometer (DCP), soaked California bearing ratios (CBR), Unified soil classification, group index, moisture contents, and dry density) were done at, or on samples gathered from, points every 500 metres around the test circuits.

The surface deflections of Highway 48, the west MFA road, and the east Local road were measured every 400 metres in both lanes, using a standard Benkleman Beam test, both pre- and post-demonstration. The surface deflection of Grid 601 was measured every 400 metres before the demonstration and every 200 metres after. The extra measurements were gathered to more fully characterise the differences in structural damage observed between the high- and low-pressure lanes. Measurement intensity was increased to every 30 metres in both lanes for one extensively damaged portion of the Grid 601 test section.

The Road Profilometer is an SDHT-developed van capable of repeatedly measuring surface profile and roughness, and reporting average values for each 50-m segment, as it is driven along a paved road. The Road Profilometer was used to generate pre- and post-demonstration surface profiles of the Westbound and Eastbound (test) lanes of Highway 48 between the west MFA road and the east Local road. Comparisons made between these rutting profiles permitted a comprehensive examination of rutting on the TMS pavement.

Surface rutting on Grid 601 and Highway 48 was manually measured before and after phase II of the demonstration at three monitoring sites. However because of the large variablity in surface and roadbed materials in the Highway 48 demonstration section, rut measurements of the TMS were disregarded in favour of the more comprehensive survey conducted by the Road Profilometer which provided extensive rutting information for the entire length of the TMS section on Highway 48. Rut growth on Grid 601 road was minimal indicating that rutting of a clay cap was a minor form of road distress compared to shearing of the clay cap, or washboard development in the traction gravel.

A video log of the pre-demonstration road condition was made of the Grid 601 and Highway 48 test sections. After the demonstration, both a video log and a detailed visual assessment of surface distress were made of these test sections. In addition, record was kept of the amount of grading maintenance and repair required by each section of the test circuit.

The 14 Saskatchewan Wheat Pool trucks used in the demonstration were 1999 Kenworth T 800 tractors pulling Lode King, 6-axle B-train, grain trailers (Figure 2). These trucks were identically configured and equipped with:

- 2-channel Redline-Eltek TPCS (not controlling steering axle tires),
- Kenworth and Hendrickson air suspensions (on tractor and trailers, respectively),
- 11R22.5 LRG Michelin tires,
- Cummins N14 electronic engines with engine retarders[1],
- Rockwell ABS brakes, and

Grid 601 was graded after every phase to insure a uniform surface cross-section before the trucks started cycling.

As most of the demonstration drivers normally use their engine retarders when braking, all drivers were instructed to use them for braking during demonstration trafficking.

- SOO Navigational Systems.

In order to obtain the desired loading on each truck, the axle loads of one truck were carefully adjusted at a local grain elevator and then the grain in each of its trailer compartments was dumped and weighed. These payloads were then put into each of the 14 test trucks in the corresponding trailer compartments. The average tare weight of the test trucks was 23.45 tonnes, the average payload was 47.00 t (standard deviation of 0.30 t), and the average Gross Combined Vehicle Weight was 70.46 t (standard deviation of 0.32 t) (Figure 3).

The following four phases were prescribed for trafficking, however, Phases III and IV were not done:
Phase I – Trafficking with unloaded trucks to demonstrate differences in washboard development on the two-lane Primary Grid road,
Phase II – Trafficking with trucks loaded to the same axle loads to demonstrate differences in road damage and maintenance,
Phase III – To demonstrate differences in road damage using 7 identical trucks operating at Primary axle weights and optimised tire pressures versus 11 trucks operating at secondary axle weights and normal highway tire pressures hauling the same payload of grain and,
Phase IV – A repeat of Phase III but with wet roadbed material on part of Grid 601.

The trucks were refuelled before and after each phase of the demonstration. An SDHT representative oversaw all refuelling ensuring that the trucks' fuel tanks were consistently filled to a common level, and recording each truck's fuel intake and odometer reading. Fuel consumption was calculated for each truck, in each phase of the demonstration, based on total distance travelled and fuel consumed. Two of the high-pressure trucks from Phase II had erroneous odometer readings and their fuel consumption rates for this phase were not estimated.

The tire manufacturer, Michelin North America (Canada) Inc. approved the weight/speed/optimised tire inflation pressures used for the demonstration. The normal highway tire pressures used in the test were determined by polling local tire shops in Regna. These settings were programmed into each truck's TPCS at the beginning of the test and, thereafter, pressures were monitored and varied, if necessary, using the TPCS. Steering axle tire pressures, which were not controlled by the TPCS, were manually set to a normal highway level for the trial. The drive and trailer tire sidewall deflections and contact footprint areas used in Phases I and II were measured.

Drive and trailer tire surface temperatures were measured by Michelin technical representatives on three loaded test trucks during the trafficking of Phase II. Each truck evaluated by Michelin employed a different set of tire pressures: normal highway pressures, optimised test pressures, and a set of pressures less than the optimised test pressures (that is, 55 psi in the drive tires and 50 psi in the trailer tires). Using an infrared camera, Michelin measured tire surface temperatures while the trucks were driving and immediately after they stopped.

3.0 RESULTS

'able 1 summarises the test inflation pressures, tire loads, sidewall deflections, and gross contact areas sed during Phases I and II of the demonstration. Most tire sidewall deflections increased by 4% - 6% /hen the inflation pressures were optimised, with the exception of the unloaded drive tires which icreased by only 2%. Increasing tire sidewall deflection has been shown to increase tire spring rates improving ride and reducing wheel hop) and also increase tire footprint contact area (improving :action and flotation on most surfaces) (Clark 1994). Optimising the test truck drive tire pressures esulted in 25% and 43% more gross contact area when loaded and unloaded, respectively. Optimising ieir trailer tire pressures resulted in 21% and 49% more gross contact area when loaded and unloaded, espectively.

'he trucks' on-board GPS navigational systems kept a record of truck movements during the trial. 'hese data were correlated with traffic estimates gathered by automatic traffic counters positioned on ie Grid 601 and Highway 48 test lanes. During Phase I, the trucks made 230 and 244 laps on the ormal highway (high) pressure and the optimised (low) pressure test circuits, respectively. During 'hase II, the trucks made 428 and 409 laps on the high and low-pressure test circuits, respectively.

'he subgrade soils of the test circuits were almost all lean clays (Unified soil classification of CL), /ith the exception of some inorganic silt of low plasticity (ML) near the junction of the east and south ocal roads and two isolated pockets of sandy clay (SC). As expected, the natural moisture contents of ie test sections increased with decreasing road standard. The TMS and Grid 601 had natural moisture ontents averaging between 13%-14%, the MFA road sections averaged 16%-17%, and the Local road ections averaged 18%-19%. Moisture contents of over 20% were measured for the deposits of iorganic silt in the Local roads. California Bearing Ratio, a measure of soil strength, consistently veraged between 5-6 for all of the lean clay samples.

.1 Phase I Road Damage.

Vashboard developed in the gravel surface of Grid 601 and became increasingly severe and idespread during the first five hours (approximately 100 passes) of Phase I. Thereafter, traffic began) displace the gravel from the wheel paths, exposing the underlying clay cap and eliminating the 'ashboard (that is, the washboard had developed only in the surface gravel). Trafficking was halted fter approximately 240 passes when damage surveys indicated that the severity and distribution of 'ashboard was decreasing rather than increasing. A detailed survey of the road surface indicated that pproximately two-thirds less washboard had developed in the low-pressure lane of Grid 601 (Fig. 4).

.2 Phase II Road Damage.

hase II trafficking occurred in three parts. The first day's trafficking was stopped in the afternoon ecause a strong crosswind caused the high-pressure trucks, heading south on Grid 601, to spray opposing vehicles (including the low-pressure trucks) with gravel. Concerns about potential accidents, vehicle damage, gravel loss,[2] and differences in lane tracking position between the high- and low-pressure trucks led SDHT to re-grade Grid 601 and continue the demonstration the next day. These concerns were eliminated the next day with a drop in wind speed, by reviewing lane tracking position with drivers, and by having the trucks form closely spaced groups that alternated travel on Grid 601. By the third day of trafficking, structural failures on the south MFA road and on the east Local road required extensive repairs and continual grading, respectively. The third part of Phase II trafficking consisted of trafficking the low-pressure circuit with all of the trucks (after lowering inflation pressures in the high-pressure trucks with their TPCS). This was done to increase the traffic count on the low-pressure circuit, which had fallen behind when trafficking was suspended to grade failing sections on the east Local road. Only fourteen more passes were made before again suspending trafficking to effect repairs. The demonstration was stopped at this time because the damaged sections in the Phase II circuits, and other weak spots in the circuits to be used for Phases III and IV, appeared unable to support the high levels of traffic necessary to visibly fail Grid 601 road's clay-capped surface.

After Phase II trafficking was halted the condition of the test circuits was assessed. Road surface distress varied with road quality and took the form of rutting, cracking, potholes, and shear failures ('push outs') in the Highway 48 TMS sections, and washboard and clay cap shear failures in the unpaved sections (Grid 601, MFA and Local roads).

The Profilometer results showed that the high-pressure TMS test section rutted 43% faster and to a slightly greater final depth than did the low-pressure section. The average rut depth of the high-pressure lane increased by 5.1 mm to 11.7 mm while the low-pressure lane's rutting increased by 2.9 mm to 11.1 mm (Figure 5). It must be noted that because of the pre-demonstration patching these two sections were structurally different. Therefore, the observed rutting differences may have resulted, to some degree, from differences in roadbed materials/moisture and surface structure rather than tire pressure.

Table 2 summarises TMS surface damage (apart from rutting) measured at the end of the Phase II trafficking. Any damage that appeared to have originated before the trial was excluded from the survey. Although a detailed survey of surface damage was not made prior to trafficking, video footage of the pre-trial condition shows that the lanes were in good repair with little cracking, and few potholes or push-outs (lateral shoving).

Longitudinal cracking may be seen as a progressive failure starting at the edges of the wheel ruts where the pavement has been bent and put into tension. This cracking begins as a single or a few cracks (i.e., *light* cracking) and then as the wheel rut deepens, cracking may spread to encompass a strip up to 0.5 m wide (i.e., *moderate* cracking). At the same time, the pavement in the wheel rut may develop longitudinal cracks joined by cross cracking, creating the distinctive "alligator" pattern (i.e., *heavy* cracking). As these alligator cracks deepen, individual cubes of pavement are loosened and may

[2] A SARM representative at the demonstration noted that gravel loss might also be influenced by changes in tire inflation pressure and should be monitored. In response, six plastic tarps (three per lane) were installed at roadside along Grid 601. Unfortunately, they were installed after the majority of gravel displacement had occurred and captured little.

e removed by traffic action (i.e., *severe* cracking). Similarly, through traffic action, potholes grow in ize from *small* (< 0.3-m diameter) to *large* and from *shallow* (<3-cm depth) to *deep*.

3oth test lanes showed an increase in rut development and with it growth of cracks as the TMS was leformed around the wheel ruts. By the end of Phase II, approximately 325 m of the low-pressure lane vas cracked and 260 m of the high-pressure lane was cracked. Most of the low-pressure lane's racking consisted of light to moderate cracking. Conversely, the high-pressure lane had more dvanced cracking. It can be observed from the data that all types of surface distress in the high-ressure lane had progressed more rapidly to an advanced stage than did the same types of failures in he low-pressure lane. For example, 58% of the high-pressure lane's potholes had become large while one of the low-pressure lane's potholes had. Similarly, 79% of the high-pressure lane cracking was eavy or severe compared with 33% for the low-pressure lane. Further, two locations in the high-ressure lane were nearing complete failure.

)eterioration of road structural strength with traffic was compared using deflection measurements. urface deflections measure the rebound of the road surface resulting from the removal of a standard veight of 80 kN (18,000 LB). The larger the rebound, the weaker the road. Heavy pavements have verage deflection values less than 0.25 mm in the fall. TMS typically have average deflections of nore than 1.5 mm in the fall. These deflections can double in the spring. Surface deflections are sually not measured on gravel-surfaced roads because of the limited applications for this data. Aeasured deflections from different gravel-surfaced roads permit relative comparisons to be made etween their structural strengths but provide no information relating to the magnitude of additional rafficking that one road could sustain relative to another.

)eflections did not indicate any change in strength of the TMS with increased truck loading, in either he high- or low-pressure test lanes. The high-pressure lane deflected an average of 1.78 mm before rafficking and 1.76 mm after trafficking. The average deflections for the low-pressure lane, before nd after trafficking, remained the same at 1.82 mm.

he low-pressure lane of the Grid 601 road had an average deflection of 1.43 mm before the emonstration, which increased with trafficking to 1.78 mm. Accounting for the number of loaded asses (409) this lane had an average deterioration rate of 0.182 mm/ 10,000 tonnes of payload. In omparison, the high-pressure lane's pre-demo average deflection of 1.45 mm increased considerably vith trafficking to 2.21 mm (Table 3). Accounting for the number of loaded passes (428) the lane had n average deterioration rate of 0.378 mm/ 10,000 tonnes of payload. These average deflections were ound to be statistically different to a confidence level of 95%. A similar analysis of the soil moisture ata indicated that the data sets for the high- and low-pressure lanes were significantly different only at 10% confidence level. The conclusion is that the difference in road damage was due to varying tire ressures rather than differences in soil conditions. Further, the low-pressure trucks were pproximately half as damaging to the Grid road as were the trucks using normal highway tire ressures.

)istress is generally greater in the outer wheel paths of a road reflecting the load shift to a truck's ight-hand wheels that takes place when driving on a road with cross slope. Grid 601 was surveyed very 500 metres and at the rut monitoring sites to estimate the average cross slope of the test lanes.

The high-pressure lane sloped downwards an average of 3.2% while the low-pressure lane was slightly more steeply sloped, on average, at 4.3%. To quantify how cross slope increased the load shifted to a truck's right-hand wheels, the Benkleman Beam truck was driven down both lanes of Grid 601 and its right-hand wheel weights were measured with portable weight scales. These measurements were then used to validate a theoretical model of load shift. The model estimated the demonstration trucks' right-hand wheel loads increased by 10% when on the high-pressure lane and by 14% when on the low-pressure lane. This difference in outer wheel path loading is expected to have accelerated the deterioration of the low-pressure lane more than the high-pressure lane, however, it is unclear by how much.

A 100% difference in average deflection existed between the adjacent lanes of the west MFA road and visual observations confirmed that a substantial portion of the clay cap was sheared in the loaded (northbound) lane (Table 4). This shearing cannot be attributed to differences in soil properties or moisture between the lanes, and is believed to be the result of trafficking of the high-pressure trucks. Because of its lower construction standard it was expected that the Local road sections would deflect more than the MFA road. The east Local road's average deflection was 4.0 mm. The side-to-side difference in average deflection was minimal on the Local road nor was any longitudinal cap shearing observed. This suggests that the high-pressure trucks caused more extensive damage to the MFA road than did the low-pressure trucks to the Local road, however, without pre-demonstration deflection data this cannot be confirmed.

3.3 Fuel Consumption.

Estimates of fuel consumption were made for both Phase I (unloaded) trucks and Phase II (loaded) trucks operating with normal highway tire pressures and optimised tire pressures (Figure 6). The unloaded trucks in Phase I had virtually identical fuel consumption rates at 60.3 and 60.4 L/ 100 km. The loaded trucks in Phase II had fuel consumption rates of 110.8 and 108.6 L/ 100 km for the high- and low-pressure trucks, respectively. A statistical analysis of the fuel consumption rates revealed that these rates were not significantly different at a 95% level of confidence. Fuel consumption is difficult to measure accurately because it is influenced by so many factors. In this case, any difference in fuel consumption caused by optimising tire inflation pressures was small enough to be obscured by other factors.

3.4 Tire Heating.

As a pneumatic tire rolls, the flexing of its carcass generates heat. In normal sustained operation, a tire will heat up to a relatively constant temperature at which the rate of heat generation is matched by its rate of heat loss. However, excessive heat build-up can result if the rate of heat loss decreases (e.g., at higher ambient temperatures) or if the rate of heat generation increases (e.g., at higher vehicle speeds or heavier tire loads). Reducing tire inflation pressures, under conditions of reduced tire load and/or travel speed, usually results in greater carcass deformation and potentially higher operating temperatures than if the tire were inflated to normal highway pressures. Tire manufacturers specify inflation pressures that optimise tire performance while maintaining operating temperatures within acceptable limits.

uring Phase II of the trial, technical representatives from Michelin's Engineering Support group ıeasured surface temperatures on three of the loaded test trucks to confirm that tire temperatures were ithin acceptable limits. Surface temperatures of the warmed drive and trailer tires, at each of the test ıflation pressures, were measured using an infrared camera. Based on tire surface temperatures, fichelin is able to estimate the higher, internal temperatures and judge whether these are acceptable. able 5 summarises the tire surface measurements.

urface temperatures were found to be hottest at the tread face between the tread blocks and ribs. Peak ırface temperatures occurred on the centreline of the tread face and decreased towards the shoulders. was noted that temperature varied less across the tread face as deflection increased (inflation ecreased). This result may be explained by the larger footprint and reduced tread face stress produced greater tire deflections (Clark 1994). As expected, reducing the trucks' tire inflation pressures did ıcrease tire temperatures. Michelin concluded that the measured tire temperatures were, in all cases, ithin acceptable operating limits. Ambient temperature influences surface temperature ıeasurements. Temperatures at the lowest tire pressure setting were not the highest because they were athered at a lower ambient temperature than the other measurements. Michelin plans to repeat the ıeasurements during the summer of 2000 when ambient temperatures are higher.

4.0 CONCLUSIONS

ince 1995, an initiative of Saskatchewan Department of Highways and Transportation (SDHT) has ermitted some truck fleets to operate with primary-highway axle weights on provincial secondary ighways under the Transportation Partnership Program. In the case of increased weight privileges the ogram requirements typically stipulate that trucks be equipped with optimised tire pressure chnology. The objective of this field trial was to demonstrate the impacts to lower standard, ıunicipal roads between trucks operated with optimised tire inflation pressures compared to identical ucks operated with normal highway tire inflation pressures.

he demonstration trial was conducted in the Rural Municipality of Walpole located five km east of e town of Wawota. Two adjacent test circuits were established on local roads of varied standard. he test circuits consisted of 3.2 km of Highway 48 (a thin membrane surfaced (TMS) pavement), 4.8 n of Grid 601 (a Primary Grid road) and eight km of Local or Main Farm Access (MFA) roads. The rid 601 road section was common to both test circuits and had two lanes. In the first phase of the emonstration, unloaded 9-axle B-trains, using high and optimised tire inflation pressures, made proximately 240 passes over the two adjacent test circuits. In the second phase of the demonstration, e same 9-axle B-trains (now loaded), again using high and optimised tire inflation pressures, made proximately 420 passes over the same two test circuits.

Analysis of data gathered during the demonstration indicated the following:

- The unloaded demonstration trucks using optimised tire pressures developed 2/3 less washboard on the Grid 601 road than when operating at normal highway tire pressures,
- Deflections are an indicator of gravel road strength deterioration,
- The deflections measured were consistent with the observed performance of the roads: the highest deflections were on sections that failed, and the smallest deflections were on sections that performed well,
- The loaded demonstration trucks using optimised tire pressures deteriorated the Grid 601 demonstration site slower than when operating at normal highway tire pressures
- The TMS structure of Highway 48 developed considerable surface damage (cracking, pot holing, and push out failures) in response to trafficking. This surface damage was observed to be of a more severe nature in the high tire pressure lane than in the optimised tire pressure lane. However, the TMS showed little structural deterioration, as indicated by the lack of change in deflection measurements with trafficking. Observed differences in rutting may be, in part, due to structural differences resulting from pre-demo patching activity.
- A fuel consumption evaluation found no significant difference between the demonstration trucks using normal highway tire pressures and those using optimised tire pressures.
- The optimised inflation pressures used in the trial were appropriate and did not lead to tire overheating.

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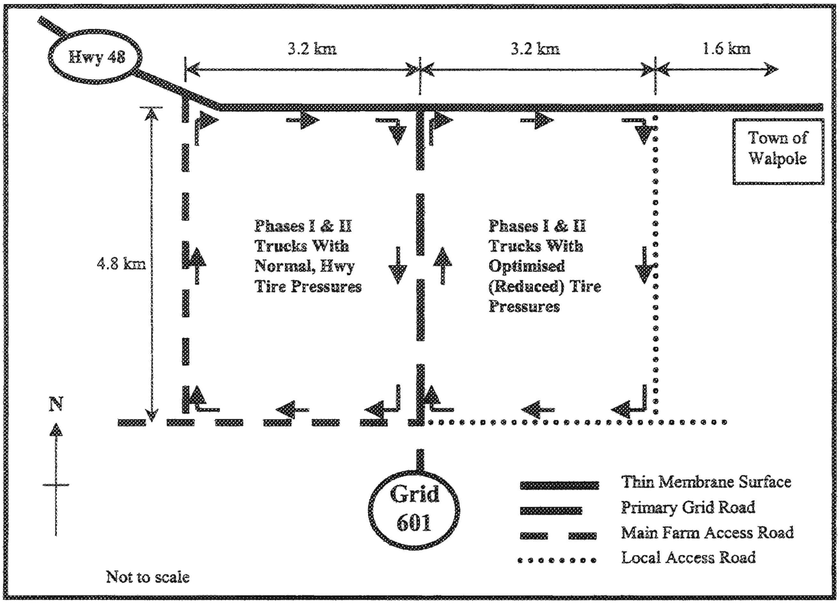

Figure 1. Field demonstration site.

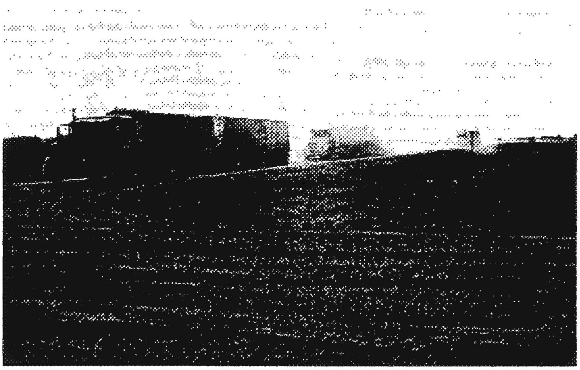

Figure 2. Test trucks at the demonstration site near Walpole.

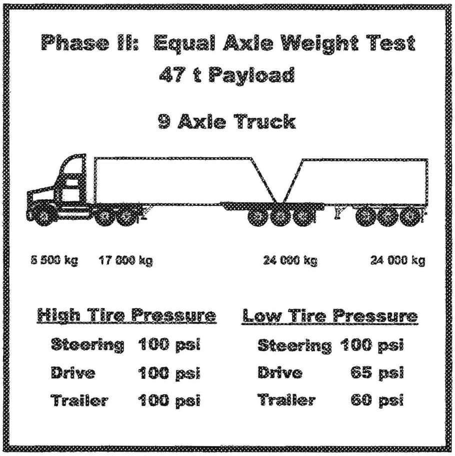

Figure 3. Phase II axle loads and tire pressures.

Table 1. Demonstration Tire Measurements

Demonstration Phase	*Tire Group**	*Tire Load (kg)*	*Cold Inflation Pressure (psi)*	*Tire Sidewall Deflection*	*Gross Contact Area (cm^2)*
I (unloaded)	*Steering*	*2450*	*100*	*13%*	*N/A*
			100	*13%*	*N/A*
	Drives	*750*	*100*	*4%*	*156.6*
			45	*6%*	*224.3*
	Lead Trailer	*533*	*100*	*0%*	*120.7*
			40	*5%*	*179.8*
	Rear Trailer	*483*	*100*	*0%*	*N/A*
			40	*5%*	*N/A*
II (loaded)	*Steering*	*2750*	*100*	*N/A*	*N/A*
			100	*N/A*	*N/A*
	Drives	*2125*	*100*	*10%*	*418.5*
			65	*14%*	*524.4*
	Lead Trailer	*2000*	*100*	*10%*	*410.0*
			60	*15%*	*498.0*
	Rear Trailer	*2000*	*100*	*9%*	*N/A*
			60	*15%*	*N/A*

- Note: All tires were new Michelin 11R22.5 Load Range G radial tires.

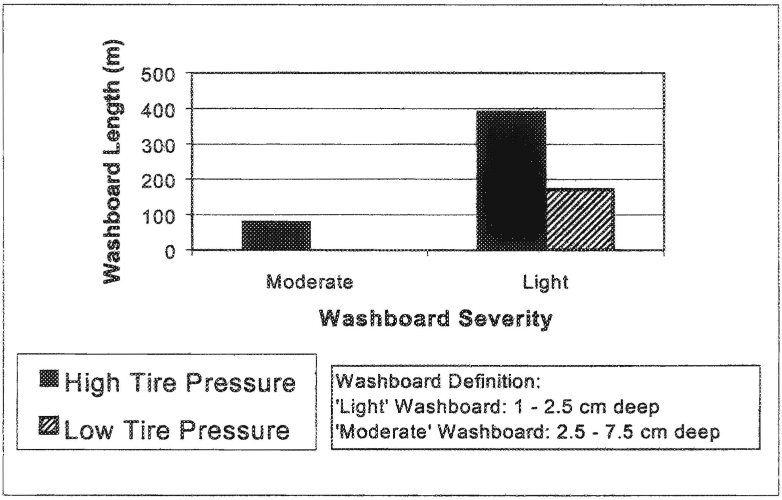

Figure 4. Washboard development on Grid Road 601 after about 240 unloaded truck passes.

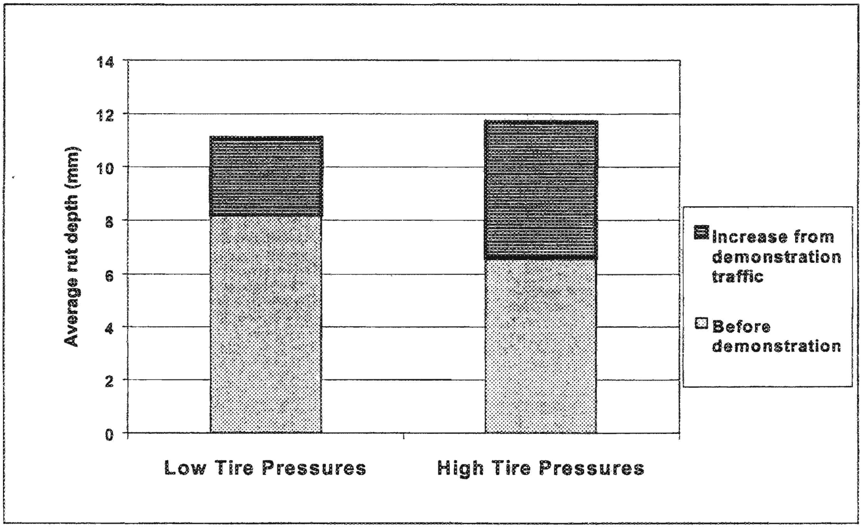

Figure 5. Rutting comparison of the TMS test sections.

Table 2. Summary of Surface Damage to Highway 48 TMS Sections

TMS Section	Longitudinal Cracking Length (m)				Pot Holes (no.)				Push Outs (m^2)
					Small		Large		
	Light	Moderate	Heavy	Severe	Shallow	Deep	Shallow	Deep	
Low-pressure	93	125	104	3	10	4	0	0	16
High-pressure	7	47	173	33	5	0	5	2	91

Table 3. Deflection Measurements: Grid 601 Road Test Section

	Average deflection (mm)	Standard deviation of average deflection (mm)
Pre-demo High-pressure Lane	1.45	0.40
Post-demo High-pressure Lane	2.21	0.78
Pre-demo Low-pressure Lane	1.43	0.42
Post-demo Low-pressure Lane	1.78	0.44

Table 4. Post-Demonstration Deflection Measurements: MFA and Local Road Test Sections

	Average deflection (mm)	Standard deviation of average deflection (mm)
West MFA road:	2.31	1.12
Loaded Lane	3.11	0.99
Unloaded Lane	1.51	0.53
East Local road:	4.00	1.75
Loaded Lane	4.00	1.77
Unloaded Lane	4.00	1.81

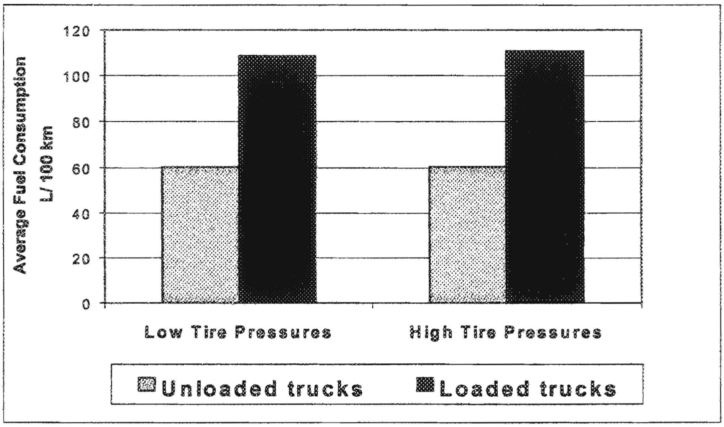

Figure 6. Fuel consumption measurements for the demonstration trucks.

Table 5. Summary of Tire Heat Measurements for the Loaded Trucks

Tire Position	Tire Size	Tire Make/ Model (Load Range G)	Inflation (psi)	Sidewall Deflection	Peak Surface Temperature (°C)*
Drive	11R22.5	Michelin XDHT	100	10%	34.4
Drive	11R22.5	Michelin XDHT	65	14%	44.2
Drive	11R22.5	Michelin XDHT	55	17%	41.1
Trailer	11R22.5	Michelin XZE	100	9%	39.6
Trailer	11R22.5	Michelin XZE	60	15%	41.7
Trailer	11R22.5	Michelin XZE	50	16%	39.3

* Note: Measured by Engineering Support, Michelin North America (Canada) Inc.